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Advanced Techniques for Signal and Image Compression/Reconstruction With Wavelets

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FOREWORD

This document reproduces a presentation made by the authors at the Signal Processing Workshop of the Maryland/Washington, DC, Chapter of the IEEE Signal Processing Society held at the University of the District of Columbia-Van Ness Campus on 24-25 March 1995. The presentation is reproduced here in an edited format.

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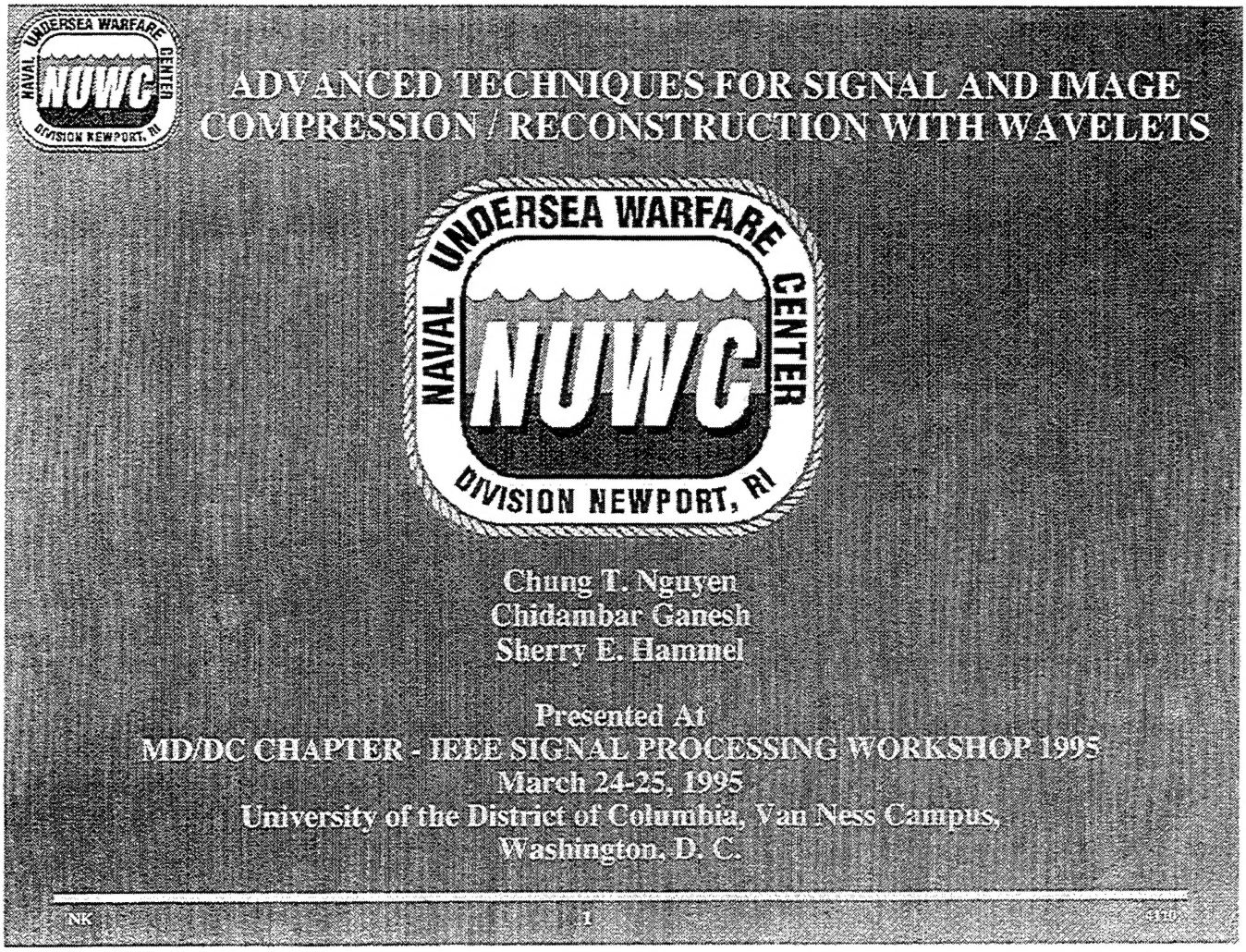
NAVAL UNDERSEA WARFARE CENTER
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ADVANCED TECHNIQUES FOR SIGNAL AND IMAGE COMPRESSION / RECONSTRUCTION WITH WAVELETS
NAVAL UNDERSEA WARFARE CENTER
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PRESENTATION OVERVIEW

- WAVELET-BASED TECHNIQUES AND ITS APPLICATIONS IN THE UNDERSEA ENVIRONMENT FOR DATA COMPRESSION
- PERFORMANCE COMPARISON WITH OTHER TRADITIONAL DATA COMPRESSION / RECONSTRUCTION TECHNIQUES
- INTRODUCTION TO THE ENERGY-BASED METHOD FOR WAVELET COEFFICIENT SELECTION
- PERFORMANCE COMPARISON BETWEEN GLOBAL THRESHOLD AND ENERGY-BASED METHODS

INTRODUCTION

- WAVELETS & WAVELET TRANSFORMS

  " The transformation of signals into a sum of small, overlapping waves offers a new method for analyzing, storing, and transmitting information". - *Gilbert Strang*

- WAVELETS & WAVELET TRANSFORMS PROVIDE SIGNIFICANT ADVANCES IN MANY SCIENCES & ENGINEERING DISCIPLINES
  - DATA COMPRESSION
    - Image Compression / Reconstruction
  - SIGNAL ANALYSIS
    - Feature Extraction
    - Detection / Classification
  - SCIENTIFIC CALCULATIONS
    - Turbulence / Chaos
    - Complex Nonlinear Differential Equations
  - MEDICAL IMAGING
  - ARTIFICIAL NEURAL NETWORKS

OBJECTIVES

THE OBJECTIVES OF THIS PROJECT ARE

- DEVELOP DATA COMPRESSION / RECONSTRUCTION TECHNIQUES USING WAVELETS, WAVELET TRANSFORMS, AND WAVELET PACKETS
- DESIGN AND DEVELOP A NEW IMPROVED WAVELET COEFFICIENT SELECTION METHOD BASED ON ENERGY CRITERIA.

THE NEW TECHNIQUE HAS TO

- PROVIDE ACCURATE FEATURE EXTRACTION IN TIME-FREQUENCY LOCALIZATION
- PRODUCE AN IMAGE WITH COMPACT CAPACITY FOR STORAGE EFFICIENCY AND RAPID TRANSMISSION
- MAINTAIN THE INTEGRITY OF THE ORIGINAL DATA

Wavelet-based Image Compression Technique

- WAVELET DECOMPOSITION OF A GIVEN IMAGE $f(x,y)$:

$$f(x,y) = \sum c_{nk} \psi_{nk}(x,y)$$

where

c_{nk} : coefficients

$\psi_{nk}(x,y)$: wavelet function

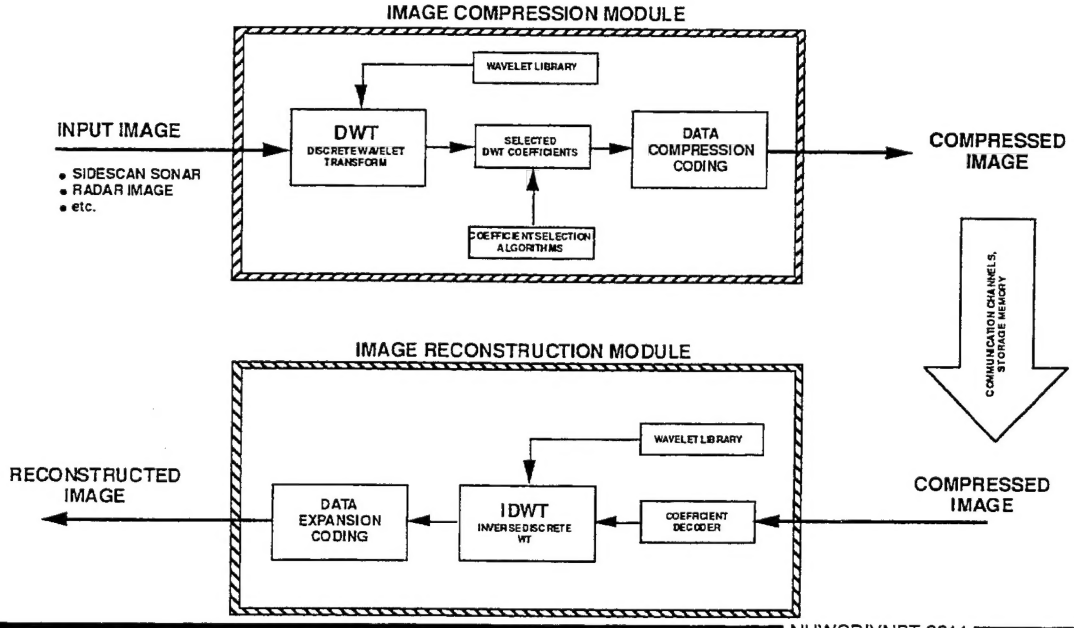
n, k : scale (frequency), location (time)

- INFORMATION CONTENT OF THE IMAGE $f(x,y)$ IS APPROXIMATED IN THE FINITE SEQUENCE OF COEFFICIENTS c_{nk}:

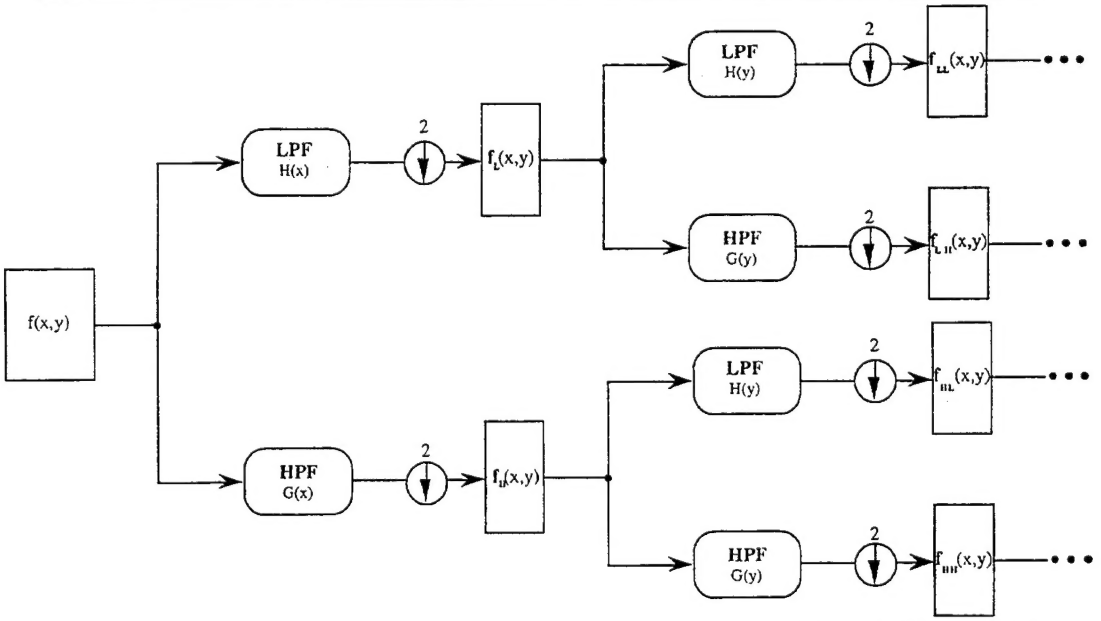
$$f \approx f_{approx} = \{c_{nk}\}$$

- UTILIZE WAVELET COEFFICIENT SELECTION ALGORITHM TO COMPRESS DATA
  - GLOBAL THRESHOLD
  - ENERGY-BASED

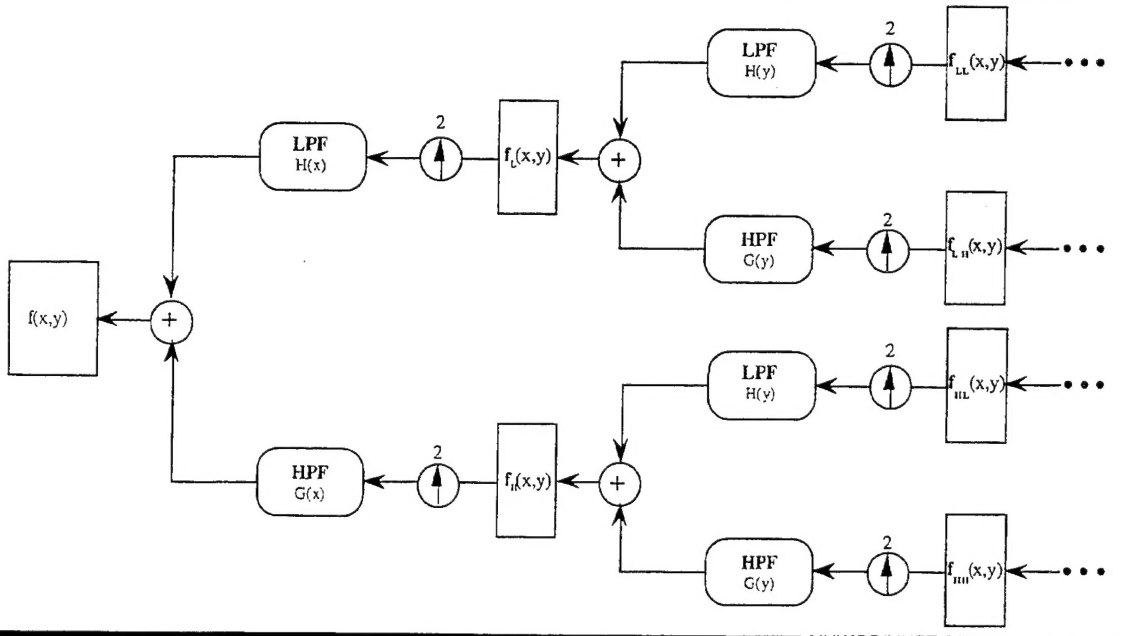
Wavelet Image Compression / Reconstruction System



Two-Dimensional Forward Wavelet Transform



Two-Dimensional Inverse Wavelet Transform



STATE OF THE ART

EXISTING METHODS FOR IMAGE COMPRESSION BASED ON GLOBAL THRESHOLDING OF WAVELET COEFFICIENTS

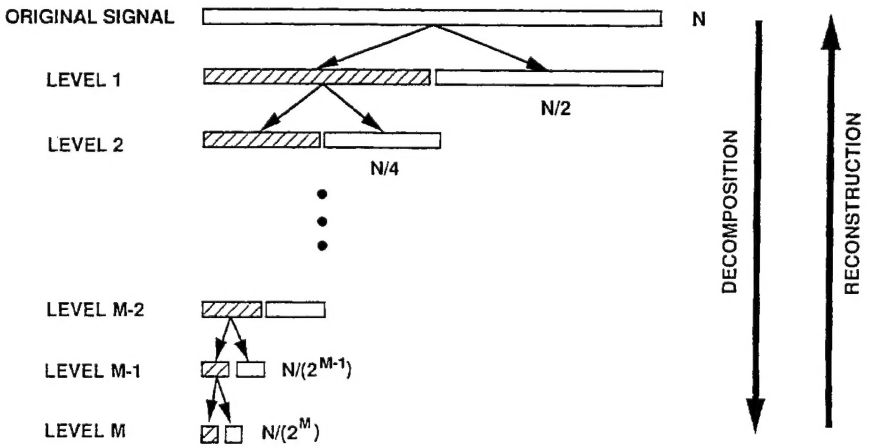
- **Mallat, S.,** *A Theory for Multresolution Signal Analysis : the wavelet representation,* ***IEEE Trans. PAMI, 1989***
- **Nacken, P.,** *Image Compression using Wavelets,* ***Wavelets: An Elementary Treatment of Theory and Applications, Elsevier Press: Amsterdam,1993***
- **Jawerth, B. and Sweldens, W.,** *An Overview of Wavelet-Based Resolution Analyses,* ***SUMMUS, Ltd. 1994.***

ENERGY-BASED WAVELET COEFFICIENT SELECTION

MOTIVATION:

- INSPIRED BY TREE STRUCTURE OF SIGNAL DECOMPOSITION AND RECONSTRUCTION WITH WAVELETS
  - Each level of the tree depends on the previous level
- EACH LEVEL OF WAVELET DECOMPOSITION TREE CONTAINS FINER APPROXIMATION AND DETAIL FROM PREVIOUS LEVEL
- UNDERWATER ACOUSTIC SIGNALS HAVE LARGEST WAVELET COEFFICIENTS CONCENTRATED IN FEW LEVELS
  - Global threshold-based selection is inadequate

WAVELET DECOMPOSITION TREE



ENERGY-BASED WAVELET COEFFICIENT SELECTION

METHOD:

- BASED ON CONSIDERATION OF MEAN ENERGY OF WAVELET COEFFICIENTS AT EACH LEVEL OF THE DECOMPOSITION TREE
- NUMBER OF WAVELET COEFFICIENTS SELECTED FROM A PARTICULAR LEVEL PROPORTIONAL TO THE MEAN ENERGY AT THAT LEVEL
- EACH LEVEL HAS ITS OWN LOCAL THRESHOLD FOR COEFFICIENT SELECTION: ENERGY CONSIDERATIONS PROVIDE A MECHANISM FOR DETERMINING THIS THRESHOLD

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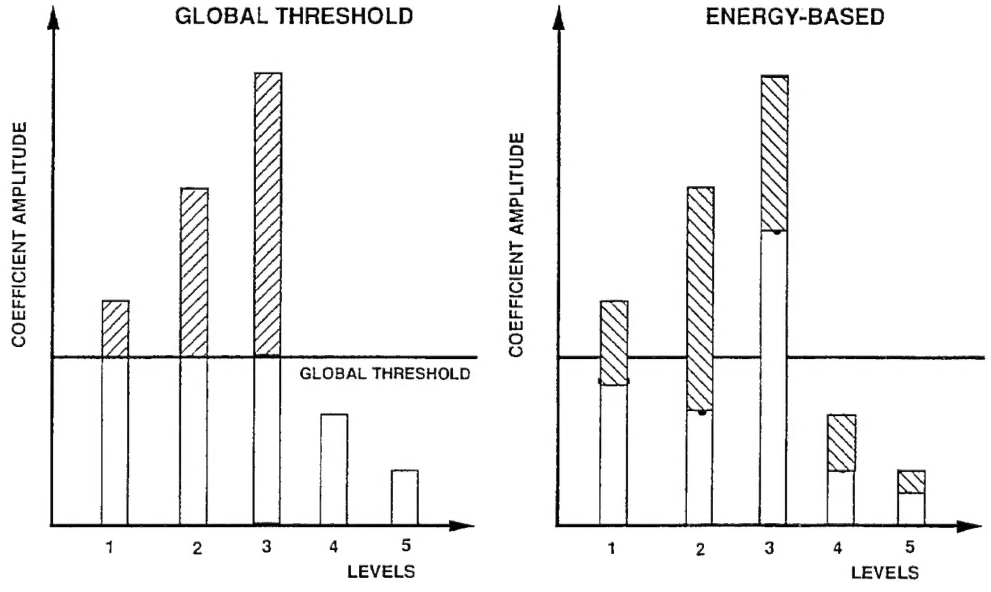
GLOBAL THRESHOLD vs. ENERGY-BASED THRESHOLD

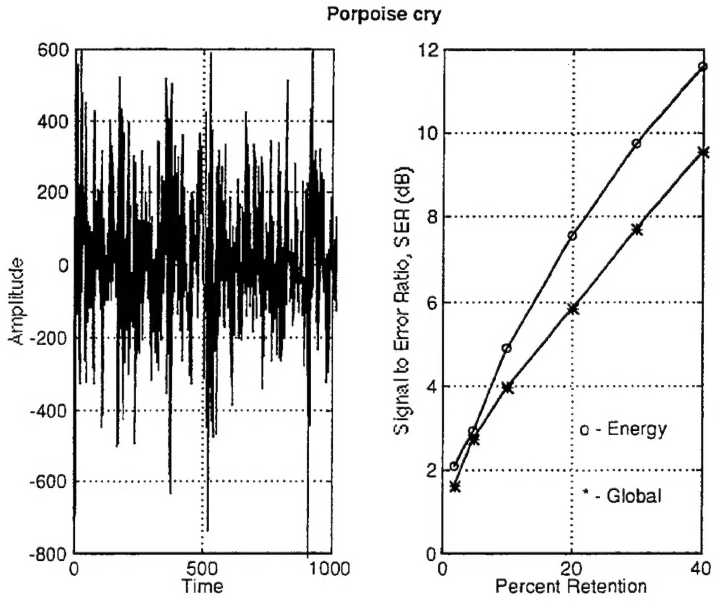


ENERGY-BASED WAVELET COEFFICIENT SELECTION

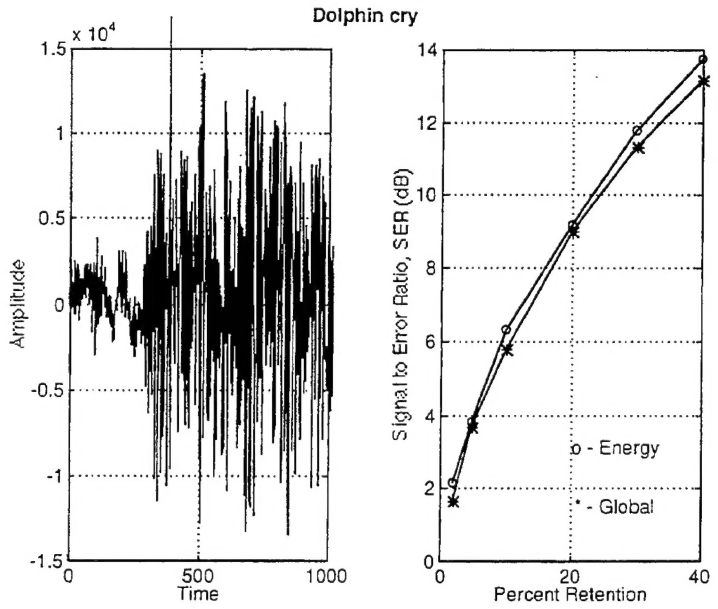
ALGORITHM:

- Let signal length = N, and Number of levels = M ($N=2^M$)
- Number of wavelet coefficients at level k is $N_k = \frac{N}{2^k}$ for k = 1, 2, ..., M
- Let the wavelet coefficients at level k be $\{c_{kj}\}$, where $j = 1, 2, ...N_k$
- Mean energy $\bar{E}_k = \frac{1}{N_k} \sum_{j=1}^{N_k} c_{kj}^2$
- If number of coefficients retained, $N_R = \frac{\text{Percent Retention}}{100} \times N$
- Number of coefficients selected from level $k = \frac{\bar{E}_k}{\Sigma \bar{E}_k} \times N_R$

PERFORMANCE COMPARISON FOR UNDERSEA BIOLOGICAL SOUNDS



PERFORMANCE COMPARISON FOR UNDERSEA BIOLOGICAL SOUNDS



ENERGY-BASED WAVELET COEFFICIENT SELECTION

DISCUSSION:

- THE NEW METHOD PROVIDES IMPROVED PERFORMANCE
- THE NEW METHOD RETAINS WAVELET COEFFICIENTS ACROSS A WIDER RANGE OF DECOMPOSITION LEVELS
- CHOICE OF OPTIMAL BASIS FUNCTION FOR A PARTICULAR TYPE OF SIGNAL REMAINS AN OPEN ISSUE
- NEW METHOD PRESENTLY APPLIED TO SINGLE-DIMENSION SIGNALS, IMAGES TO BE ANALYSED.

CONCLUSIONS

- WAVELET-BASED METHODS PROVIDE SIGNIFICANT PERFORMANCE ENHANCEMENT OVER TRADITIONAL FOURIER-BASED METHODS FOR DATA COMPRESSION
- ENERGY-BASED METHOD SERVES AS A LOCAL COEFFICIENT SELECTION TECHNIQUE
- ENERGY-BASED METHOD PROVIDES IMPROVED PERFORMANCE OVER THE TRADITIONAL GLOBAL THRESHOLD METHOD